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Forest Management for Resilience and Adaptation

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Summary

U.S. forests are primarily temperate forests, often with relatively few species dominating over wide areas. Such forests respond and adapt to an array of environmental factors—sunlight levels and duration, temperature, precipitation, and a multitude of disturbances (e.g., fires, pests, and storms)—and these factors could be further altered by long-term shifts in natural climate variability and climate change. Many domestic forests are already under stress from drought, severe wildfires, and insect epidemics. Changing conditions and disturbances could diminish the goods and services that forests provide—timber, clean water, scenic vistas, carbon sequestration, and much more. Forests can be subject to management techniques to improve their resilience and adaptability, to assure continued production of the economically desired ecosystem goods and services.

Congress provides management direction and funding for federal forests and financial and technical assistance for management of nonfederal forests. To date, such legislative direction and funding have at most indirectly encouraged management that promotes resilient forests. Congress could decide to broaden its role in promoting resilient and adaptable forests. However, thus far, no broad-based legislation has been introduced calling for direct federal forest management and nonfederal forestry assistance to sustain forests in the face of changing conditions.

Biologically diverse forests are generally more resilient (better able to recover from changes and disturbances) and more adaptable (better able to respond to changing conditions), because they have a broader biological base from which to respond. Diversity occurs at the genetic level (among trees of a given species), at the species level (among trees in a stand), and at the stand level (among the ages and sizes of trees in a stand). Many are concerned that climate change and increased climate volatility may be too rapid for natural adaptation and migration to sustain production of the desired goods and services, because some species require special habitat conditions and because forest fragmentation from human development hinders forest migration. Others argue that natural variability is sufficient to sustain forests, even in the face of climate change.

Research and monitoring are important components of understanding the extent and success of forest management efforts to promote resilient and adaptable forests. Management efforts could then respond to changing forest conditions by adjusting traditional forestry practices (e.g., prescribed burning, thinning, timber harvesting, tree planting, and more) or even by taking more intensive action to assist forest adaptation (e.g., reducing habitat fragmentation, creating habitat corridors, and assisting species relocation). A question for Congress and resource managers is whether or how to fund and implement research and monitoring programs to provide information for forest management in a time of changing conditions.

Contents

Figures

Appendixes

Contacts

Forests respond to various factors, such as amount of sunlight, temperature levels and variations, precipitation amounts and timing, and a host of disturbances (fire, pests, invasive species). Changes in climatic patterns—whether natural or human-induced—could affect these factors, possibly increasing temperatures, altering the hydrologic cycle, and exacerbating forest disturbances. Such changes could alter the dynamic balance of forest ecosystems, shifting forest habitats north and to higher elevations. Many are concerned that the natural ability of U.S. temperate forests to adapt to changing climate conditions may be insufficient to sustain production of desirable ecosystem services—timber, recreation, water, carbon sequestration, and more. Some predictions show climate-induced habitat shifts outpacing the natural rate of forest migration and dispersal, making forests vulnerable to pests, diseases, and invasive species and to extreme events, like wildfires, all of which can damage ecosystem services, such as water quality and desired animal habitats.[1] Others contend that ecosystems have been able to adapt in the past, and they will be able to adapt again.

Forest management can affect the ability of forests to respond and adapt to changing conditions. To date, legislative direction and funding for management of federal lands and for federal assistance in managing nonfederal lands has, at most, indirectly encouraged management for resilience (recovery from) and adaptation to changing conditions. Legislation on forest management generally has been either broadly focused—very general direction in climate or energy bills, for example—or specific to regional or local forestry problems, such as the extensive mountain pine beetle infestation in the northern and central Rocky Mountains. This report focuses on management approaches that might be employed to promote forests that are resilient and adaptable to disturbances and changing conditions, regardless of the cause.

Forests can be managed to improve their resilience and adaptation to disturbances and possible climatic change and variability. Diverse forests can sustain the production of desired ecosystem services, such as clean water, wildlife habitat, recreational opportunities, timber and biomass, carbon sequestration, and more. Forest management for diversity could include changes in wildfire management, forest health, timber production, and forest regeneration; more intensive adaptation practices include reducing forest fragmentation, providing habitat corridors, and assisting migration. These practices are discussed in **Appendix B**.

Forests of the United States

Domestic U.S. forests are dominated by relatively few forest types (compared to tropical forests), but contain an array of species mixes, as described in **Appendix A**. Within each of the many temperate forest types, often relatively few tree species dominate the overstory, and more tree and shrub species occur in the understory. The species and species mixes have evolved and adapted to survive within certain climatic conditions and complex ecological relationships. Historic temperature patterns and forest dynamics suggest that habitats are changing and will continue to change. However, some have expressed concerns that the predicted rate of change will exceed the natural adaptive rate, decreasing total temperate forest area.[2] Thus, changes in climatic patterns

[1] J. McLachlan et al., "A Framework for Debate of Assisted Migration in an Era of Climate Change," *Conservation Biology,* vol. 21, no. 2 (2007), pp. 297-302.

[2] L. Joyce et al., "Chapter 17: Potential Consequences of Climate Variability and Change for the Forests of the United States," in *Climate Change Impacts on the United States,* ed. National Assessment Synthesis Team (Cambridge: Cambridge Univ. Press, 2001), pp. 489-524.

are seen as potentially altering domestic forests and possibly depreciating their value in providing economically valuable goods and services.[3]

The 750 million acres of U.S. forests are owned and managed by many entities—the federal government, states, local governments, corporations, and other private landowners. The relative dominance of these landowner groups varies regionally, as shown in **Appendix A**. Federal forests are most common in the West. States and local governments own significant forestlands, especially in the Midwest (Minnesota, Michigan, and Wisconsin) and mid-Atlantic (Pennsylvania and New York) regions. Corporate forests tend to be concentrated in the most timber-growing productive areas—the Pacific Coast and the South—and are generally managed for industrial wood products. Other private forests dominate in the eastern regions. These landholdings vary widely in size and purpose, from small holdings (e.g., summer homes) that may occasionally sell timber for extra revenue to tens of thousands of acres managed by hunt clubs, land trusts, and other organizations.

The principal federal forest management agency—the Forest Service in the Department of Agriculture (USDA)—is attempting to address the possible effects of climate change on land and resource management.[4] In July 2010, the Forest Service issued its *National Roadmap for Responding to Climate Change.*[5] This strategic plan provides general direction for national forest adaptation, for agency capacity-building, and for cooperation among landowners since climate changes affect all forests.

The management intensity and expertise applied to private forests vary widely. The Forest Service and Natural Resources Conservation Service (also in USDA) have numerous programs to provide technical and some financial assistance to non-corporate private forest owners, directly and through state forestry organizations. Assistance programs could provide support for forest resilience and adaptation by non-corporate forest owners.

Impacts of Climate Variability and Change on Temperate Forests

Domestic forests have experienced significant changes in the past 30 years or more, with greater tree mortality from drought, wildfires, and a host of insects and diseases.[6] Even under modest greenhouse gas (GHG) emissions scenarios, climate change is projected to increase temperatures and climate volatility, alter hydrology and water availability, and substantially expand the extent and impacts of disturbances.[7] Change is not inherently bad, and can in many instances lead to desirable new forests and ecosystem services. The new forests would likely be a mix of existing natural forest species and exotic species, and the result could be radically different ecosystems. It

[3] This report does not address managing forests to mitigate climate change (i.e., managing forests to increase carbon sequestration), although many of the forestry practices can enhance carbon sequestration and thus reduce the impacts of carbon emissions on climate. For more information, see CRS Report RL31432, *Carbon Sequestration in Forests*; CRS Report RL34560, *Forest Carbon Markets: Potential and Drawbacks*; and CRS Report R41144, *Deforestation and Climate Change*.

[4] For a more thorough summary of federal efforts by the Forest Service and other federal departments and agencies, see T. Cruce and H. Holsinger, *Climate Change Adaptation: What Federal Agencies Are Doing*, Pew Center on Global Climate Change, Washington, DC, November 2010, http://www.pewclimate.org/docUploads/FederalGovernmentLeadershiponAdaptation_Nov2010.pdf.

[5] See http://www.fs.fed.us/climatechange/pdf/roadmap.pdf.

[6] C. Allen et al., "A Global Overview of Drought and Heat-Induced Tree Mortality Reveals Emerging Climate Change Risks for Forests," *Forest Ecology and Management*, vol. 259 (2010), pp. 660-684.

[7] P. Gonzalez et al., "Forest Carbon Densities and Uncertainties from Lidar, QuickBird, and Field Measurements in California," *Remote Sensing of Environment*, vol. 114, (2010), pp. 1561-1575.

is unclear whether these new ecosystems would continue to provide timber, wildlife habitat, and other economically beneficial values.

Possible Temperature Changes

There is a broad scientific consensus that average temperatures in the lower atmosphere have increased over the last century, and this trend is expected to continue and possibly increase.[8] Forest species are adapted to specific habitats, generally defined by a particular pattern of temperature, hydrology, and other climatic factors. Warming temperatures could both alter existing habitats and their corresponding species mixes and spur habitats and species to migrate. In general, rising temperatures are expected to cause habitats to migrate upslope and expand northward, while contracting at their southern extremes.[9] Generally, oak-hickory, oak-pine, ponderosa pine, and arid woodland habitats are expected to expand, while alpine and subalpine habitats, like spruce-fir and aspen-birch, are likely to decrease.[10] One study has estimated that, by the end of the century, oak-hickory forests in southern New England could move 70-150 miles north, substantially increasing these forests and decreasing the area of other forest types (e.g., maple-beech-birch and spruce-fir forests).[11]

Research on forests of the northeastern United States provides an example of what has already happened and what more might happen. In Vermont's Green Mountains, temperatures rose by 1.1º C between 1964 and 2004, leading the spruce-fir and maple-beech-birch forest types to move upslope by more than 300 feet in elevation over the 40-year period.[12] Even larger temperature increases are projected to occur for the region by 2100.[13] Such temperature increases could mean that, by the end of the century, oak-hickory forests in southern New England could move north and increase their area by 50% to 400%.[14] This would likely reduce the area of maple-beech-birch forests (and maple syrup production) by a quarter and move them upslope by more than 250 feet in elevation. This would coincide with retreat of nearly 2000 feet higher in elevation for boreal conifer (spruce-fir and white-jack-red pine) forests, and thus their elimination from many mountaintops. A similar retreat in alpine-tundra habitats has been reported in the Sierra Nevada Mountains of California.[15] Conversely, a downslope expansion of several species in California reportedly occurred despite warmer temperatures, because of an accompanying shift in hydrologic patterns (more rain and snow at lower elevations).[16]

[8] For a discussion of the science of climate change, see CRS Report RL34266, *Climate Change: Science Highlights*.

[9] D. Spittlehouse and R. Stewart, "Adaptation to Climate Change in Forest Management," *BC Journal of Ecosystems and Management*, vol. 4, no. 1 (2003).

[10] Joyce et al., "Consequences of Climate Change for U.S. Forests."

[11] G. Tang and B. Beckage, "Projecting the Distribution of Forests in the New England Response to Climate Change," *Diversity and Distributions*, vol. 16, (2010), pp. 144-158.

[12] B. Beckage et al., "A Rapid Upward Shift of a Forest Ecotone During 40 Years of Warming in the Green Mountains of Vermont," *PNAS*, vol. 105, no. 11 (March 8, 2008), pp. 4197-4202.

[13] A. Evans and R. Perschel, "A Review of Forestry Mitigation and Adaptation Strategies in the Northeast U.S.," *Climatic Change*, vol. 96, no. 1-2 (2009), pp. 167-183.

[14] Tang and Beckage, "Distribution of Forests in the New England Response to Climate Change."

[15] Gonzalez et al., "Ecosystem Vulnerability to Climate Change."

[16] S. Crimmins et al., "Changes in Climatic Water Balance Drive Downhill Shifts in Plant Species' Optimum Elevations," *Science*, vol. 331 (January 21, 2011), pp. 324-327.

Possible Hydrologic Changes

Experts predict that temperature changes will probably be accompanied by hydrologic changes, adding more stress to trees in some areas, while benefitting trees in other areas. Warming trends are expected to increase the volatility of precipitation events and could lead to both more rain and more drought.[17] There is less agreement on precipitation projections among climate change models than there is on temperature predictions.[18] For example, for the Northeast, precipitation predictions range from roughly 25% increases by 2100, to little change or small regional decreases.[19]

The severity and frequency of drought is expected to increase, especially in areas where drought is already an issue. This trend will likely add stress to U.S. forests, reducing tree growth and increasing tree mortality. "The primary immediate response of trees to drought is to reduce net primary production [plant growth].... Under extended severe drought conditions, plants die."[20] Cases of widespread tree mortality have often occurred during the most severe droughts. Two examples are the extensive tree mortality in the southern Appalachian Mountains and the Great Plains during the dust-bowl droughts of 1920s and 1930s, and the die-off of multiple pine species in the Southwest during the 1950s drought.[21] Climate models also project more frequent and intense ice storms, wind storms, and heavy rainfall, [22] all of which can increase disturbances and tree mortality.

Furthermore, increasing temperatures are expected to shorten U.S. winters, decreasing snowpack and hastening snowmelt, albeit with substantial regional variation. Early snowmelt and reduced snowpack are expected to increase summer moisture deficits (seasonal droughts), increasing stress on forests, increasing tree mortality, and making forests more vulnerable to disturbances.[23] Early snowmelt also has been shown to increase the danger of landslides, flash floods, and wildfire.

Forest Disturbances

Disturbances are events that kill anywhere from a few trees to extensive stands, and include sudden events (e.g., severe storms and floods) as well as more drawn-out occurrences (e.g., wildfires, insect or disease infestations, and drought). Disturbances of various sorts occur naturally in temperate ecosystems. Disturbances kill and knock down trees, providing seedlings

[17] G. Meehl et al., "Chapter 10: Global Climate Projections," in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (New York: Cambridge Univ. Press, 2007), p. 750.

[18] K. Redmond, "Climate Variability and Change as a Backdrop for Western Resource Management," in *Bringing Climate Change Into Natural Resource Management: Proceedings of a Workshop*, Gen. Tech. Rept. PNW-GTR-706 (Portland, OR: USDA Forest Service, March 2007), pp. 5-40.

[19] National Assessment Synthesis Team, *Climate Change Impacts on the United States: Potential Consequences of Climate Variability and Change—Overview: Northeast* (Washington: U.S. Global Climate Change Research Program, 2000), pp. 40-45.

[20] Joyce et al., "Consequences of Climate Change for U.S. Forests," p. 501.

[21] Allen et al., "Climate Change Risk for Forests."

[22] Spittlehouse and Stewart, "Forest Adaptation to Climate Change."

[23] D. McKenzie et al., "Climatic Change, Wildfire, and Conservation," *Conservation Biology*, vol. 18, no. 4 (2004), pp. 890-902.

access to sunlight and space; when they occur at a modest scale, disturbances allow forests to adapt far more rapidly than without the disturbance.[24]

Pests—insects and diseases—are U.S. forests' greatest natural disturbance element. Insects and diseases, both native and exotic, can limit tree growth and kill trees. In 2008, nearly 9 million acres of trees (more than 1% of all U.S. forests) were killed by insects and diseases, a 32% increase from 2007.[25] Unusually hot, dry weather patterns over a few years can increase insect survival rates, and are believed to be responsible for increased insect outbreaks in forests in the U.S. Southwest and West.[26] Current data and models suggest that global warming will result in the redistribution of insect pests, resulting in the invasion of new habitats and forest types.[27] The mountain pine beetle is an example of how climate variability and change can convert a regionally native insect into an invasive species.[28] For the beetles, long, cold winters limit overwinter survival, and therefore have geographically restricted the insect.[29] Warmer temperatures accelerate reproductive success, increasing the infestation while reducing the trees' ability to defend themselves.[30] The current infestation has reached parts of northern Canada previously unaffected, and possibly allowing the beetle to invade eastern Canada and the eastern United States, where it has never existed before.

Wildfires are another significant natural forest disturbance. Climate variability has historically been a key factor for wildfires in the western United States.[31] Higher temperatures and drier conditions are expected to bring more severe fire weather.[32] In addition, the variability between fire seasons is expected to increase.[33] Warmer springs and earlier snowmelt have been shown to provide a productive growing season (i.e., a wet spring) often followed by a seasonal drought, turning the large quantities of biomass (plant matter) from the growing season into fuel for a potential forest fire.[34]

Some forests regenerate after extensive disturbances with fewer species, usually the strongest survivors, in a process called synchronization. A synchronized forest generally has a relative dearth of species and only one or a few age classes. Increased climate volatility, with more frequent and more extreme events to disturb forests,[35] could increase the synchrony of U.S.

[24] Allen et al., "Climate Change Risk for Forests."

[25] USDA Forest Service, *Major Forest Insect and Disease Conditions in the United States 2008 Update*, FS-933, Washington, DC (Sept. 2009).

[26] J. Logan et al., "Assessing the Impacts of Global Warming on Forest Pest Dynamics," *Frontiers in Ecology and the Environment*, vol. 1, no. 3 (2003), pp. 130-137.

[27] Logan et al., "Global Warming and Forest Pest Dynamics."

[28] See CRS Report R40203, *Mountain Pine Beetles and Forest Destruction: Effects, Responses, and Relationship to Climate Change*.

[29] D. Leatherman et al., *Mountain Pine Beetle*, Colorado State Univ. Extension, no. 5.528, at http://www.ext.colostate.edu/pubs/insect/05528.html.

[30] D. Leatherman et al., *Mountain Pine Beetle*.

[31] McKenzie et al., "Climatic Change, Wildfire, and Conservation."

[32] J. Littell et al., "Climate and Wildfire Area Burned in Western U.S. Ecoprovinces, 1916-2003", *Ecological Applications*, vol. 19, no. 4 (2009), pp. 1003-1021; McKenzie et al., "Climatic Change, Wildfire, and Conservation."

[33] Joyce et al., "Consequences of Climate Change for U.S. Forests."

[34] A. Westerling et al., "Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity," *Science*, vol. 313 (August 18, 2006), pp. 940-943.

[35] P. Backlund et al., *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States*, Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Synthesis and Assessment Product 4.3, Washington, DC, May 2008, p. 5,

forests, increasing their vulnerability by reducing the number and variety of a forest's defenses. For example, mountain pine beetles attack lodgepole pines of more than 5 inches in diameter; the synchronized regeneration of lodgepole pine forests following severe fires a century ago is a major factor in the current mountain pine beetle epidemic and extensive forest mortality.[36]

Atmospheric Changes

Greenhouse gas emissions can also affect forests. Increased CO_2 and nitrogen levels are expected to increase average growth rates (net primary productivity) in U.S. forests.[37] This would likely increase carbon sequestration by U.S. forests, mitigating or offsetting some greenhouse gas emissions.[38] Furthermore, increased atmospheric concentrations of CO_2 can also increase plant water-use efficiency.[39] This could mitigate stress from any declines in precipitation, but higher temperatures and longer growing seasons also increase total water demands for sustaining plant growth.[40] In addition, higher ozone concentrations can reduce growth rates, while nitrogen deposition can acidify soils, reducing forest productivity and degrading water quality.[41]

Because of the possible counteracting effects of increasing carbon, nitrogen, and ozone levels in the atmosphere and of increasing atmospheric carbon and temperature, it is unclear whether atmospheric changes would benefit or harm forests. One report noted that "increases in biomass across many forest types … [are] attributed to climate change. However, without knowing the disturbance history of a forest, growth could also be caused by normal recovery from unknown disturbances."[42]

Forest Resilience and Adaptation

The Importance of Biodiversity

Forest resilience—the ability to respond to and recover from disturbances and changing conditions—and forest adaptation—the ability to change or migrate in response to disturbances and changing conditions—historically have been key to ecosystem sustainability.[43] Conversely, unsuccessful adaptation may lead to extinction.[44] Diversity among and within plant and animal species in an area is an important aspect of providing for resilience and adaptation. Biodiversity has been described as "the fundamental building block of the services that ecosystems deliver."[45]

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http://www.globalchange.gov/publications/reports/scientific-assessments/saps/sap4-3.

[36] M. Kauffman et al., *The Status of Our Scientific Understanding of Lodgepole Pine and Mountain Pine Beetles—A Focus on Forest Ecology and Fire Behavior*, GFI Tech. Rept. 2008-2 (Arlington, VA: The Nature Conservancy, 2008).

[37] J. Aber et al., "Forest Processes and Global Environmental Change: Predicting the Effect of Individual and Multiple Stressors," *BioScience*, vol. 51, no. 9 (September 2001), pp. 735-751.

[38] Joyce et al., "Consequences of Climate Change for U.S. Forests."

[39] Evans and Perschel, "Forestry Mitigation and Adaptation Strategies in the Northeast."

[40] Joyce et al., "Consequences of Climate Change for U.S. Forests."

[41] Joyce et al., "Consequences of Climate Change for U.S. Forests."

[42] S. McMahon et al., "Evidence for a Recent Increase in Forest Growth," *PNAS*, vol. 107, no. 8 (February 23, 2010), pp. 3611-3615.

[43] C. Millar et al., "Climate Change and Forests of the Future: Managing in the Face of Uncertainty," *Ecological Applications*, vol. 17, no. 8 (2007), pp. 2145-2151.

[44] S. Running and L. Mills, *Terrestrial Ecosystem Adaptation*, Resources for the Future, Washington, DC, June 2009, p. 11, http://www.rff.org/RFF/Documents/RFF-Rpt-Adaptation-RunningMills.pdf.

[45] Backlund et al., *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity*,

In contrast, fewer species tend to concentrate or exacerbate risks.[46] Higher levels of biodiversity generally contribute to ecosystem health and stability by providing a broader base, or toolbox, from which to respond, recover, or adapt. In other words, diverse ecosystems are more stable (resilient) over time and more adaptable (better able to evolve) in response to changing conditions, because they contain more variations that can potentially survive.[47]

Biodiversity occurs at three primary levels. The lowest or most basic level is *genetic diversity*—the variations in genetic composition among trees of the same species. Because of this variability, some individuals are better adapted to certain conditions—more tolerant to drought, more resistant to pests, and so forth. For example, individual white pine trees vary significantly in their resistance to white pine blister rust. [48] Trees from the seeds of resistant individuals are also resistant, and planting resistant trees is a common approach to reducing pest problems. This approach is being tried to reestablish the American chestnut, which was virtually eliminated from eastern U.S. forests by an introduced fungus (the chestnut blight) early in the 20th century.[49] Clones and genetic monocultures are an extreme form, with no genetic diversity whatsoever (each plant is genetically identical to every other plant). Such practices have been used in agriculture for decades, and the condition occurs naturally in some plants (e.g., many aspen stands are multiple trees from a common rootstock, and thus are effectively monocultures); however, the lack of genetic variation in crops and livestock has also long been recognized as increasing risks from pests.[50]

The second level of biodiversity is *species diversity*—the variations in species within a stand of trees. Species diversity in temperate forests is modest, compared to the diversity of tropical forests. Nonetheless, as described in **Appendix A**, most U.S. temperate forest types include several major species. Even those types with a single dominant species typically contain several additional species. Species diversity tends to protect forests against pest epidemics, as most pests are host-specific, attacking only one or a few closely related species. Species diversity promotes the adaptability of forests to pests, fire, drought, and other disturbances, since different species respond differently to the disturbances.

The third or highest level of biodiversity is *stand diversity*—the variation in tree ages and sizes among stands of trees, as well as in species. As with genetic and species diversity, stand diversity (also known as asynchrony) promotes forest resilience by providing a variety of conditions to respond to changes and disturbances. For example, the mountain pine beetle (discussed above) only infests lodgepole pine trees greater than 5 inches in diameter. Thus, a lodgepole pine forest containing stands of varying sizes can withstand an epidemic, because some stands will not become infested.

Synthesis and Assessment Product 4.3, p. 9.

[46] Millar et al., "Climate Change and Forests of the Future."

[47] G. Blate et al., "Adapting to Climate Change in United States National Forests," *Unasylva 231/232*, vol. 60 (2009), pp. 57-62.

[48] B. Kinloch and G. Dupper, "Genetic Specificity in the White Pine—Blister Rust Pathosystem," *Phytopathology* vol. 92, no. 3 (2002), pp. 278-280.

[49] See the American Chestnut Foundation webpage, http://www.acf.org/history.php.

[50] See M. Altieri, *Biodiversity and Pest Management in Agroecosystems* (Binghamton, NY: Haworth Press, 1994); and D. Pimentel and A. Wilson, "Non-Indigenous Species: Crops and Livestock," in *Encyclopedia of Pest Management*, ed. D. Pimentel, vol. 2 (Cleveland, OH: CRC Press, 2007), pp. 400-403.

Possible Congressional Role

Congress could have an expanded role in promoting resilient and adaptable forests. Congress establishes direction and provides funding for federal forests and for financial and technical assistance for management of nonfederal forests. For federal forests, current congressional direction indirectly encourages management that promotes resilient forests. For the USDA Forest Service (59% of federal forests), the basic direction is in the Multiple Use-Sustained Yield Act of 1960 (P.L. 86-517; 16 U.S.C. §§528-531): to produce a sustained yield of the multiple uses (goods and services) from the lands, without impairing long-term productivity. While not explicit direction to manage the national forests to assure resilience and diversity, the direction for sustained yields implies management for adaptation to changing conditions, including a changing climate. However, this and many other laws govern Forest Service management activities, and some observe that the total legislative direction is at best cumbersome and at times even contradictory.[51]

Congress also authorizes and funds technical and financial assistance for managing nonfederal forests.[52] However, the federal government has no direct role in management of nonfederal forests; regulation of forestry practices on private lands is exclusively a state prerogative and responsibility.[53] Nonetheless, provisions enacted in the 2008 farm bill (P.L. 110-246, the Food, Conservation, and Energy Act of 2008) require states to develop assessments of forest conditions, trends, threats, and priorities to receive funding.[54] The national priorities for assistance include managing forests for multiple goods and values; protecting forests from disturbances; and enhancing production of public benefits. Climate change was listed explicitly as an issue for forestry assistance—clearly direction for federal assistance for nonfederal forest management to provide adaptable, resilient forests.

Legislation in the 112th Congress could affect management for forest adaptation, though to date no bills have been introduced with broad forest management implications. None of the bills introduced in the 111th Congress provided guidance for federal management or assistance for forest adaptation to climate change. At a broad scale, the climate cap-and-trade bills in the 111th Congress, such as S. 1733 and H.R. 2454, generally included funding for forest adaptation, but with very little guidance on what to do or how to use the funding.[55] At the other end of the scale, bills were introduced to address specific regional or local forest health problems, such as the mountain pine beetle epidemic in the northern and central Rocky Mountains (see, for example, H.R. 5192, S. 2724, and S. 2798).

Limits to Natural Adaptation

While forest ecosystems can adapt to changing climatic conditions over the long run (a century or more), the desired goods and services provided by forests may well be disrupted as forest

[51] U.S. Dept. of Agriculture, Forest Service, *The Process Predicament: How Statutory, Regulatory, and Administrative Factors Affect National Forest Management*, Washington, June 2002, http://www.fs.fed.us/projects/documents/Process-Predicament.pdf.

[52] See CRS Report RL31065, *Forestry Assistance Programs*.

[53] This is not to suggest that the federal government has no influence over private forest management. Many laws, such as the Clean Water Act and the Endangered Species Act, affect the opportunities and responsibilities of private forest landowners, but there is no federal regulation of nonfederal forestry practices, per se.

[54] See CRS Report RL33917, *Forestry in the 2008 Farm Bill*.

[55] See CRS Report R40911, *Comparison of Climate Change Adaptation Provisions in S. 1733 and H.R. 2454*.

ecosystems adapt. Some are concerned that the expected rate of climate change may be too abrupt for U.S. temperate forests to adapt or migrate without substantial losses.[56] Tree species dispersal is very slow, due to long generation intervals, and thus conditions may change more quickly than tree species can disperse. Most trees alive today will still be alive in 2090, when global climate models predict significantly higher temperatures and altered hydrological patterns.[57]

Species and populations most likely to be harmed by climate change include habitat specialists that require special conditions; populations of trees on the southern and/or southeastern edges of their habitat, such as the boreal forests of the northeastern United States; species located in fragmented habitat (see "Fragmentation and Corridors," below); and species that are poor colonizers or dispersers (i.e., that have difficulty regenerating).[58] Ecological community interactions play an important role in determining ecosystem migration. Such community interactions as species competition, nutrient chain relationships, and symbiotic relationships may limit migration.[59]

Forest management could assist resilience and adaptation to disturbances and to the accelerated rate of change projected by most climate models. Diverse, sustainable forests can continue to produce the desired array of ecosystem services, such as clean water, wildlife habitat, recreational opportunities, timber and biomass, carbon sequestration, and more.

Management for sustainable forests suggests that "ecological adaptation" might replace "ecological restoration" as the underlying management approach to conservation and sustained production. For many years, various interests have approached forest management under the presumption that restoring forest ecosystems to historical conditions, commonly defined as pre-Euro-American settlement, is the best way to promote and sustain ecological integrity and forest productivity.[60] However, climate change might substantially alter regional climates from the conditions of the last several centuries, or even millennia.[61] Thus, "restoration" of historic conditions could be unsustainable or infeasible. Instead, forest management approaches could emphasize responses to disturbances to provide and enhance forest resilience and diversity at the genetic, species, and stand levels.

Monitoring and Responding to Results

The potential effects of climate variability and change on forested ecosystems are broad and varied. Uncertainty over changes in temperature, levels and timing of precipitation, and catastrophic events, combined with incomplete knowledge of ecological systems, leads to even greater uncertainty about natural ecological responses. Efforts to manage uncertainty include several continuing activities: conducting research on ecological conditions and changes; monitoring the results of climate change and of management efforts; and adjusting management based on the information gathered.

[56] Millar et al., "Climate Change and Forests of the Future."

[57] B. St. Clair and G. Howe, "Genetic Options for Adapting Forests to Climate Change," *Western Forester*, vol. 54, no. 1 (Jan/Feb 2009), pp. 9-11.

[58] B. Griffith et al., "Climate Change Adaptation for the US National Wildlife Refuge System," *Environmental Management*, vol. 44, (2009), pp. 1043-1052.

[59] McLachlan et al., "A Framework for Debate of Assisted Migration in an Era of Climate Change."

[60] R. Keane et al., "The Use of Historical Range and Variability (HRV) in Landscape Management," *Forest Ecology and Management*, vol. 258, (2009), pp. 1025-1037.

[61] Millar et al., "Climate Change and Forests of the Future."

Research and Information

Reducing threats, increasing diversity, and improving habitat connectivity are based on relatively simple, broadly accepted understandings of species, ecosystems, and the possible effects of climate change.[62] However, there is substantial uncertainty as to the ability of forests to recover from and/or adapt to changes, due at least in part to the uncertainty of climate change impacts themselves. Annual variability and the unknowns about the long-term nature of climate change suggest an approach of monitoring changes in conditions and results, and of adjusting management to assist forests in recovering from and adapting to changing conditions. However, such research and monitoring can also be costly.

The research and information needed to manage for forest resilience and adaptation cover broad subjects. Four topic areas have been identified by researchers as significant research gaps:

1. *Baseline Data.* Baseline data on the current distribution of species and species mixes do not exist for many U.S. forests. Some argue that baseline data are necessary to measure the effects of changes in climate, to inform management strategies, and to improve predictions about the effects of changes.[63]
2. *Climate Change Predictions.* Reduced uncertainty in climate change predictions could facilitate decision making. Generally, uncertainty in predicting the magnitude and extent of climate change restrains action. Some scientists maintain that reducing uncertainty in predictions of temperature and precipitation could make forest adaptation management less risky and less uncertain.[64]
3. *Forest Ecosystem Responses.* Management strategies could be informed by further research on forest ecosystem responses to stressors, such as chronic or acute water stress, belowground processes, habitat migration, pests and diseases, and growth rate responses to atmospheric changes.[65] Historic and paleo-ecological data can document past forest responses to different climatic conditions, and thus may be useful for predictions about future ecological changes.[66]
4. *Adaptive Management Efficacy.* Relatively little is known about the effectiveness of adaptive management.[67] It is a relatively modern development in forestry, and research on the effects of forest management can take several years to decades, due to the long generation cycles of forests.

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[62] J. Lawler, "Resource Management in a Changing and Uncertain Climate," *Frontiers in Ecology and the Environment*, vol. 8, no. 1 (2010), pp. 35-43.

[63] Griffith et al., "Adaptation for Wildlife Refuges;" McLachlan et al., "Assisted Migration in an Era of Climate Change."

[64] Blate et al., "Adapting to Climate Change in United States National Forests."

[65] Allen et al., "Climate Change Risk for Forests"; McMahon et al., "Evidence for a Recent Increase in Forest Growth."

[66] Lawler, "Resource Management in a Changing and Uncertain Climate"; P. Landres et al., "Overview of the Use of Natural Variability Concepts in Managing Ecological Systems," *Ecological Applications*, vol. 9, no. 4 (1999), pp. 1179-1188.

[67] T. DeLuca et al., "The Unknown Trajectory of Forest Restoration: A Call for Ecosystem Monitoring," *Journal of Forestry*, vol. 108 (September 2010), pp. 288-295.

Monitoring Conditions and Results

A lack of existing systematic measurement and monitoring programs may constrain the ability of scientists and managers to determine if forests are adapting to climatic and other changes, either naturally or as a result of management strategies. On-the-ground monitoring can provide insight into the stresses experienced by trees and the nature and direction of ecosystem change, thus providing information to guide management responses.[68]

Several monitoring programs exist, some of which might be a useful beginning for examining climate variability and impacts on forests, and the effectiveness of natural and managed adaptation, but none are specifically designed for this purpose.[69]

- The USDA Forest Service's Forest Inventory and Analysis Program (FIA) began in 1917. FIA reports on the status and trends of tree species size and volume. For all classes of forest land ownership, FIA measures and reports total tree inventory, growth, mortality, and removals by harvest, as well as wood production and utilization rates by various products.[70] FIA is comprised of a series of statistically validated permanent forest plots. It is widely considered to be successful at accurately measuring timber data, which is what it was designed to do. While valuable for some purposes, its has limited utility for identifying baseline forest conditions and measuring other changes because of its historic emphasis on commercial timber volumes.
- The European Union's intensive forest health monitoring network, EU/ICP-Forests Level II, is another ecosystem monitoring example. This program monitors habitat shifts for a wide spectrum of species across the European Union (about 1.07 billion acres) with 6,000 monitoring plots.[71] It has also provided data and scientific rationale for policy decisions, promoted public awareness of ecosystem health, and created an early warning system for environmental issues, such as forest destruction, biodiversity changes, and deposition (precipitation of pollution).[72]
- The Northwest Forest Plan was created by a record of decision for the Bureau of Land Management and the Forest Service by the Clinton Administration in 1994. This adaptive management plan instructed forest managers to experiment with, monitor, and interpret forest management strategies over an area of 10 million acres of federal forests in the Pacific Northwest.[73] The plan established a large-scale regional program to monitor old-growth forests, northern spotted owl and marbled murrelet habitats, watersheds, and socioeconomic effects on local communities, tribes, and others.[74] After 10 years, an assessment of the plan

[68] Millar et al., "Climate Change and Forests of the Future."

[69] Backlund et al., *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity*, Synthesis and Assessment Product 4.3, p. 4.

[70] See FIA website, http://fia.fs.fed.us/.

[71] McLachlan et al., "Assisted Migration in an Era of Climate Change."

[72] D. Durrant et al, *European Forests and the Environment: The Work and Achievements of EU/ICP Forests*, http://www.icp-forests.org/pdf/folder.pdf.

[73] See E. Tuchmann, *The Northwest Forest Plan: A Report to the President and Congress* (Portland, OR: USDA Forest Service, 1996).

[74] L. Joyce et al., "Chapter 3—National Forests," in *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources*, Final Report, Synthesis and Assessment Product 4.4, U.S. Climate Change Science

> criticized managers for exercising too much caution in adaptive management strategies and experimentation, but found the established large-scale monitoring system to be extremely useful in both expected and unexpected ways.[75] For example, a balance sheet resulting from the plan showed that forest growth outpaced losses to timber harvest, fire and other disturbances, something that many foresters had expected but that surprised others.

Other landscape-scale programs include monitoring that could prove useful to assessing ecological responses to management and environmental changes; examples include the Sierra Nevada Forest Plan and the Southern Appalachian Forest assessment. In addition, other USFS programs provide information on forest conditions and responses to stimuli. For example, the National Fire Plan and the Forest Health Monitoring Program (focused on insects, diseases, and invasive species) could provide consistent approaches for assessing changing conditions and the results of management. Nonetheless, these efforts are geographically or topically limited, and may be of limited value for determining baselines and changing conditions.

Management Response

Forest management, whether plantations for timber production or protected natural areas, affects species diversity and stand structures. Traditional forestry practices can be modified to emphasize diversity for resilient and adaptable forests. For example, wildfire management can be modified to include prescribed burning and *appropriate management response* (see **Appendix B**) to increase natural fire benefits. Similarly, timber harvesting, thinning, and stand regeneration practices can emphasize species for adaptable responses to disturbances and changing conditions, while forest certification is a means of providing oversight to assure sustained forest productivity. Some advocate more intensive actions to support forest adaptation, such as reducing forest fragmentation, protecting habitat corridors, and even managing species relocation. These possibilities are discussed in more depth in **Appendix B**.

Many argue that forest management strategies need to respond and adjust to new insights about forest health from research and monitoring.[76] The uncertainties of projecting future climate change and its effects on ecological systems suggest flexibility in management plans. Forest adaptation likely could be improved with up-to-date climate science and information about local changes for land managers. Some suggest that managers should be involved in monitoring changes in the forests themselves, because they see and know what changes are occurring.[77] To do so, forest monitoring efforts would need to be expanded and the focus altered. However, such monitoring might be costly, and could divert managers' attention from decision making and implementation.

"Adaptive management" is a commonly described management style of taking action, assessing the results, and modifying the future actions based on the results.[78] Passive adaptive management implements the "best apparent management option," with feedback from research and monitoring to adjust future management activities.[79] Active adaptive management allows for experimentation

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Program, Washington, DC, June 2008, http://www.climatescience.gov/Library/sap/sap4-4/final-report/.

[75] B. Bormann et al., "Adaptive Management of Forest Ecosystems: Did Some Rubber Hit the Road?" *BioScience*, vol. 57, no. 2 (2007), pp. 186-191.

[76] McLachlan et al., "Assisted Migration in an Era of Climate Change."

[77] Millar et al., "Climate Change and Forests of the Future."

[78] See CRS Report R41671, *Adaptive Management for Ecosystem Restoration: Analysis and Issues for Congress*.

[79] J. Anderson et al., "Watershed Restoration—Adaptive Decision Making in the Face of Uncertainty," in *Strategies for*

with monitoring, and allows management strategies to be altered quickly in response to new information—both research and on-site results—to address expected and ongoing changes. Forest management may need to be adaptive. Although important lessons can be learned from the past, past conditions might not be replicable in a changing future.

Restoring River Ecosystems: Sources of Variability and Uncertainty in Natural and Managed Systems, ed. R. Wissmar et al. (Bethesda, MD: American Fisheries Society, 2003), pp. 205-206.

Appendix A. Domestic U.S. Forests

Most domestic U.S. forests are temperate forests, with relatively few tree species (compared to tropical forests), but various species mixes. The text box below describes the temperate forests that dominate most of the United States. Alaska contains mostly boreal forests of hemlock-Sitka spruce along the southern coast and panhandle, and of spruce-birch mixes in the interior. The United States also includes some tropical forests in southern Florida and Hawaii.

Within each of the many temperate forest types, a few to several tree species dominate the overstory, and several to many additional plant species occur in the understory. These species and species mixes have evolved and adapted to habitats with certain climatic conditions and complex ecological relationships. Historical evidence of temperature patterns and forest dynamics suggest that forest habitats have changed and are continuing to change. Some observers, however, are concerned that the rate of climate change exceeds the natural adaptive rate, and will cause a decrease in total temperate forest habitat.[80] If so, climate change could substantially change domestic forests and possibly degrade their value in providing desired goods and services.

Temperate Forest Types in the United States

Several forest types dominate each of the ecological regions of the United States. The Northeast and North Central regions contain 172 million acres of forest, dominated by oak-hickory forests (32% of the area) in the southern portions of the regions and maple-beech-birch forests (31%) in the northern portions. Other important northern forest types include aspen-birch forests (10%), spruce-fir forests (9%), elm-ash-cottonwood forests (7%), and white-jack-red pine forests (6%). In the Southeast and South Central regions, the 215 million acres of forest are dominated by oak-hickory forests (39%) and loblolly-shortleaf pine forests (26%), but also include oak-pine forests (11%), oak-gum-cypress forests (10%), and longleaf-slash pine forests (6%). The highly productive 87 million acres of forest in the Pacific Coast states are more variable; they are dominated by Douglas-fir forests (24%) in the northern portions and western hardwood forests (23%) in the southern portions, but also include ponderosa pine forests (11%), fir-spruce forests (9%), pin□yon-juniper forests (7%), hemlock-Sitka spruce forests (6%), and more. The 145 million acres of forest in the Intermountain region are also highly variable—dominated by pin□yon-juniper forests (33%), but including fir-spruce forests (15%), Douglas-fir forests (19%), western hardwood forests (18%), ponderosa pine forests (11%), and lodgepole pine forests (8%).

Source: W.B. Smith et al., *Forest Resources of the United States, 2007: A Technical Document Supporting the Forest Service 2010 RPA Assessment* (Washington: USDA Forest Service, 2009), Tables 5 and 6, pp. 163-164, 171.

U.S forests are valuable assets. Forests provide many goods and services (collectively known as "ecosystem services"), such as timber, clean water, recreation, and more. The ecosystem services provided by forests may be vulnerable, if forests cannot adapt to the changing climate. However, management to ameliorate disturbances and to increase forest diversity and resilience could help avoid or minimize such possible losses.

Most climate scientists and forestry experts agree that climate change could have significant ecological consequences, altering species mixes and increasing forest disturbances. While U.S. temperate forests have existed when the earth had significantly higher CO_2 concentrations and was significantly warmer, and will undoubtedly exist in a different climatic future, the issue is the nature and rate of the transitions from current forest conditions to future conditions. Forests take decades to adapt, and thus could be in transition for the next century or longer.[81] The important

[80] Joyce et al., "Consequences of Climate Change for U.S. Forests."

[81] Gonzalez et al., "Global Patterns in the Vulnerability of Ecosystems Due to Climate Change."

question is: will U.S. forests continue to provide economically valuable ecosystem services as they adapt to climate and other changes?

Although changing climatic conditions would likely affect all regions, the impacts are likely to vary by region and within regions, due to differences in latitude, hydrology, and topography, as well as in the impacts on individual species and species mixes. Particular species could be affected by specific disturbances, significantly altering the ecosystems. One historic example of the impact of an invasive species is the chestnut blight, which virtually eliminated chestnuts that had accounted for as much as a quarter of the trees in oak-hickory forests a century ago. As discussed further below, climate change makes the introduction of invasive species more likely. Different forest types are likely to be affected differently by climate change and may require different management strategies to promote their adaptation.

Domestic Forest Ownership

U.S. forests are owned and managed by many entities, including the federal government, states, local governments, corporations, and other private landowners. The relative importance of these landowner groups varies regionally, as shown in **Figure A-1**. The largest federal forest management agency is the Forest Service, in the Department of Agriculture (USDA). These forests are primarily in the West, although the Forest Service is the largest landowner in the eastern regions. The Department of the Interior (DOI), particularly the Bureau of Land Management (BLM), administers most of the other federal forestlands, although the Departments of Defense and Energy also manage federal forests. Several states and local governments also own significant amounts of forestland; this is especially the case in the Midwest (Minnesota, Michigan, and Wisconsin) and Mid-Atlantic (Pennsylvania and New York) regions.

Private forests are more common in the North and South regions. Corporate forests are substantially concentrated in the most productive areas for timber growing—the Pacific Coast (Washington, Oregon, and California) and the South—and are generally managed for industrial wood products. Other private forests—also called non-industrial private forests—dominate in the eastern regions. These landholdings vary widely in size and purpose, ranging from a few acres for a second home on a forested lakeshore or a woodlot on a farm, which occasionally provide timber revenues for the landowners, to tens of thousands of acres managed by hunt clubs, land trusts, and other organizations, where timber production is often a secondary or residual result of management.

Forest Management Programs

The Forest Service and the Department of the Interior are addressing the effects of climate change on federal land and resource management.[82] The Forest Service released its *National Roadmap for Responding to Climate Change* in July 2010.[83] This is a strategic plan that establishes general management guidance for national forest adaptation and for carbon mitigation from agency activities. It also acknowledges the need to build agency capacity and seeks to build cooperation among landowners recognizing that climate change affects all forests. The Interior Department established a Climate Change Task Force, which developed three reports analyzing the impacts of climate change and identifying relevant options for DOI agencies.[84] The department has also

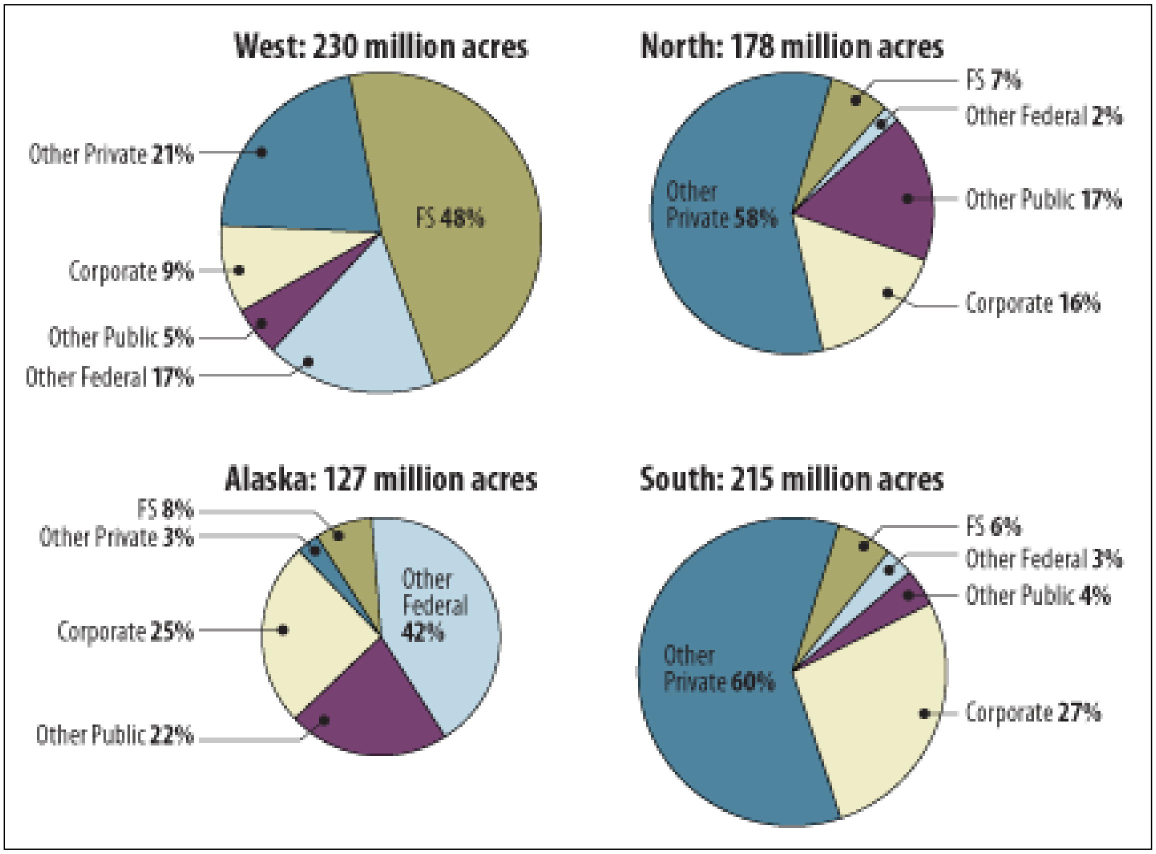
[82] See Cruce and Holsinger, *Climate Change Adaptation: What Federal Agencies Are Doing*.

[83] See http://www.fs.fed.us/climatechange/pdf/roadmap.pdf.

[84] See http://www.usgs.gov/global_change/doi_taskforce.asp.

created a climate change response council, eight regional climate science centers, and a network of landscape conservation cooperatives for managing climate-change impacts.[85]

Figure A-1. U.S. Forest Ownership by Region



Source: W.B. Smith et al., *Forest Resources of the United States, 2007*, USDA Forest Service, Gen. Tech. Rept. WO-78, Washington, DC, 2009, pp. 154-156, http://nrs.fs.fed.us/pubs/gtr/gtr_wo78.pdf.

The management of private lands varies widely. Some, such as many corporate timberlands, are managed intensively and rely on substantial forestry expertise. Others, including many of the non-industrial forests, are largely left to grow with little management effort. The Forest Service and Natural Resources Conservation Service (also in USDA) have numerous conservation programs that can provide technical and some financial assistance to private forest owners. Some assistance is available directly from the federal agencies, while some is provided through state forestry agencies. To the extent that these agencies recognize and are attempting to respond to climate variability and change, federal assistance programs to private forest owners are likely to provide information and support for forest adaptation.

[85] See http://www.doi.gov/whatwedo/climate/index.cfm.

Appendix B. Management for Forest Adaptation

Diversity of species and stand structures allow forests to be resilient and adaptable, whether intensively managed plantations for timber or protected natural areas. Traditional forestry practices, such as wildfire management and timber harvesting, can be tweaked to emphasize structures and diversity that enhance the ability of forests to respond and adapt to change. Landowners undertake many activities in response to disturbances, especially wildfires and insect and disease epidemics. Wildfire and forest health management practices to control damages and prevent or ameliorate possible damages affect biodiversity, and thus can be used to increase the resilience and adaptability of forests. Timber management can enhance or reduce forest adaptability, depending on the practices used and how they are implemented. More intensive actions, such as providing migration corridors or even assisting forest migration, may be warranted in some circumstances. Finally, monitoring is an important aspect to determine how forests are responding to management activities and changing conditions, to assure the sustained production of desired forest ecosystem services.

Wildfire Management

Wildfires are natural disturbances in nearly all temperate forests, with wide variations in intensity and frequency. For much of the 20th century, fire was seen as inherently destructive to forests, and efforts were made to control and prevent all wildfires. This history of aggressive fire suppression, combined with historic logging and grazing practices, have made some ecosystems susceptible to unnaturally intense wildfires.[86] Alternative wildfire management approaches—altering fire protection and control and reducing fuel levels—can enhance the resilience and adaptability of some forest ecosystems.[87]

Fire Protection and Control

Wildfires do not burn uniformly; when burning within natural parameters (which may be difficult to define), wildfires tend to increase species and stand diversity and thus enhance forest resilience and adaptability.[88] Thus, some have advocated that fires which do not threaten lives and resources be allowed to burn, saving taxpayer dollars and providing the biodiversity that comes from natural wildfires.[89] In addition, because of weather conditions, fuel loads, and in some ecosystems, natural vegetation patterns, many crown fires cannot be controlled, although sometimes such fires can be guided away from high value areas and structures.

Federal land management agencies have developed an approach that allows some wildfires to burn—the *appropriate management response (AMR)*. The approach "encompasses all the response actions necessary to manage a wildfire … from monitoring a fire at a distance to

[86] M. Bekker and A. Taylor, "Fire Disturbance, Forest Structure, and Stand Dynamics in Montane Forests of the Southwestern Cascades, Thousand Lakes Wilderness, California, USA," *Ecoscience*, vol. 17, no. 1 (2010), pp. 59-72; McKenzie et al., "Climatic Change, Wildfire, and Conservation."

[87] Some observers have noted that protecting structures from wildfire in the wildland-urban interface is largely unrelated to wildfire management. For more information on protecting homes from wildfire, see CRS Report RL34517, *Wildfire Damages to Homes and Resources: Understanding Causes and Reducing Losses*, and CRS Report RS21880, *Wildfire Protection in the Wildland-Urban Interface*.

[88] Bekker and Taylor, "Fire Disturbance, Forest Structure, and Stand Dynamics in Montane Forests."

[89] Christopher Lancette, "Poll Shows Changing Attitudes Toward Wildfire," The Wilderness Society, Oct. 22, 2008, http://wilderness.org/content/poll-shows-changing-attitudes-toward-wildfire.

intensive suppression actions."[90] AMR, at least in theory, allows fire managers to aggressively suppress fires, or portions of fires, that threaten lives, property, and resources; to use fire control methods to direct fires away from threatening situations; and to use fires, or portions of fires, to achieve management objectives, such as reducing fuel loads, when lives, property, and resources are not threatened. Critics of federal fire management, however, suggest that implementation of AMR has been rather limited.[91]

Fuel Reduction Efforts

Some ecosystems have unnaturally high biomass fuel levels, because of aggressive suppression of all wildfires and past logging and grazing practices. In some ecosystems, reducing fuel levels to lower the severity of wildfires to historically natural intensities can generate the benefits of stand asynchrony and heterogeneity associated with natural wildfires.[92] Fuel reduction efforts have been the focus on much of the debate over increasingly severe wildfires in recent years.[93] The two primary tools for reducing fuels are prescribed burning and mechanical thinning (described below under "Timber Management").

Prescribed burning is deliberately setting fires in specific areas under identified conditions. (Some include wildfires not actively suppressed under Appropriate Management Response, described above, as prescribed burning, but the federal agencies use the term "wildland fire use" for such situations.) Prescribed burning is widely used for fuel management, because it reduces biomass (the fuels) to ashes (minerals), which act as fertilizer. It is particularly effective at reducing the smaller fuels, especially in the arid West where deterioration by decomposers (insects, fungi, etc.) is often very slow, and may well get slower if changing climatic conditions exacerbate drought. In fact, prescribed burning is the only treatment that directly reduces the fine and small fuels that are known to facilitate wildfires. Prescribed burns may also reduce the risk and extent of disturbances like wildfires and infestations of pests, diseases, or invasive species.[94] Prescribed burns alter forest structure by removing some of the understory in a spatially heterogeneous manner, increasing diversity for more resilient, adaptable forests.

Prescribed burns are not perfect tools. They are not fully controlled actions, and occasionally escape and cause extensive damages; for example, the Cerro Grande fire that burned 237 houses in Los Alamos, NM, in May 2000 was an escaped prescribed burn. Also, some are concerned that the emissions from prescribed burns may exacerbate climate change. Both wildfires and prescribed burns release large quantities of CO_2. Advocates of prescribed burning contend that the burns merely shift the timing of fire, not the total amount burned—that the CO_2 released by prescribed burning equals what would have been released by wildfires without prescribed burns. Further, many argue that prescribed burns significantly reduce total CO_2 emissions by reducing the frequency of severe fires.[95]

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[90] National Fire and Aviation Executive Board, Memorandum to: fire Management, Subject: Clarification of Appropriate Management Response, June 20, 2007.

[91] FUSEE (Firefighters United for Safety, Ethics and Ecology), *Issue Paper: Implementing Appropriate Management Response (AMR)*, Eugene, OR, http://fusee.org/docs/AMR/AMR%20Issue%20Paper.pdf.

[92] N. Berg and D. Azuma, "Bare Soil and Rill Formation Following Wildfires, Fuel Reduction Treatments, and Pine Plantations in the Southern Sierra Nevada, California, USA," *International Journal of Wildland fire*, v. 19 (2010), pp. 478-489; and Blate et al., "Adapting to Climate Change in United States National Forests."

[93] See CRS Report R40811, *Wildfire Fuels and Fuel Reduction*.

[94] Spittlehouse and Stewart, "Forest Adaptation to Climate Change."

[95] C. Wiedinmyer and M. Hurteau, "Prescribed Fire as a Means of Reducing Forest Carbon Emission in the Western

Forest Health Management

Forest health management is the term used for preventing, controlling, or eradicating insects, diseases, and invasive species. In contrast to wildfire management, the tools for forest health management are highly variable and often specific to a particular pest. For example, insects might be defoliators (destroying leaves or needles) or borers (infiltrating under the bark); diseases might defoliate or damage tree roots. Many pests are host-specific, attacking only one species of tree, while others can infest a wider array of hosts; for example, Douglas-fir tussock moth only feeds on Douglas-fir trees, while white pine blister rust can infest all white pine species, and gypsy moths can feed on nearly any tree species.[96] Invasive species might be insects or diseases, or they could be plants or animals that displace or feed on native species.

The tools for forest health management generally include manual controls, chemical controls, and biological controls. Manual controls include cutting and removing infested trees (often called salvage and sanitation harvesting, and discussed below) or invasive plants. Chemical controls include pesticides (insecticides, herbicides, etc.) of various sorts; special care is commonly taken with chemical use, because of the potential for effects on human health.[97] Biological controls include an array of species to introduce pathogens, parasites, or predators to eliminate the target species. These approaches have varying degrees of specificity in controlling pests—manual methods can be very specific, but many chemicals are broad-spectrum. Biological controls can be very host-specific (e.g., parasitic wasps that only live on a particular species) or more broadly controlling (e.g., Bt [Bacillus thuringiensis] infects all Lepidoptera [moths and butterflies]).[98] A longer-term strategy, and the only effective one for some diseases, is the selection and propagation of plants that are resistant to the disease or pest.

Forest health management tools and practices can enhance or limit forest resilience and adaptation. Forest health management can be quite complicated, as the various tools are only effective for certain pests; for example, chemical methods are often ineffective for controlling borers and root diseases, while a different biological control may be needed for each pest. Because of the variety of tools, it is difficult to categorize the effects of the tools on resilience and adaptability. Nonetheless, forest health can be improved generally, if the management tools are selected and implemented to remove invasive species and expand the native genetic, species, and stand diversity of forests.

Many observers distinguish between endemic or native species of insects and diseases and exotic or foreign pests, and suggest that eradicating exotic and invasive species would generally improve the ecological sustainability of ecosystems. However, changing conditions can lead native pests into new, adjoining ecosystems; for example, warmer winters have allowed the mountain pine beetle to migrate into jack pine stands of northern Alberta, where it has not occurred previously. Should an endemic species that moves into a new ecosystem be considered an exotic species, or should this migration be considered natural? This is an important but difficult determination for those who support eliminating invasive species.

United States," *Environmental Science and Technology*, vol. 44, no. 6 (2010), pp. 1926-1932.

[96] U.S. Dept. of Agriculture, Forest Service, Forest Health Protection, "Managing Native Insects & Diseases," http://www.fs.fed.us/foresthealth/management/fhm-natives.shtml.

[97] U.S. Dept. of Agriculture, Forest Service, Forest Health Protection, Pesticide Management & Coordination, "Health & Safety," http://www.fs.fed.us/foresthealth/pesticide/health.shtml.

[98] U.S. Dept. of Agriculture, Forest Service, Forest Health Protection, "Biological Control," http://www.fs.fed.us/foresthealth/biologicalcontrol/index.shtml.

Timber Production and Management

Timber production and management, or silviculture, has been an historically important part of forest management. Silvicultural decisions determine the timber harvesting, thinning, and reforestation practices employed on forest land—industrial plantations as well as private woodlots and publicly owned forests.[99] These decisions affect the diversity of both existing and future forests by choosing which (if any) trees to cut, which trees to let grow, and in what patterns, thus determining the genetic, species, and stand diversity of forests. In addition, forest management certification is a means to assess and assure sustained forests over the long term.

Timber Harvesting

Timber harvesting is cutting and removing trees, usually to produce wood products (lumber, plywood, paper, etc.) Decisions about the cutting system to use, the rotation age (the age or size when trees is to be cut), and cutting unit size and dispersal affect forest diversity at all levels. Standard cutting systems typically yield even-aged stands, where all or most of the trees are in one or two age classes, and uneven- or all-aged stands, where the trees vary in age and size.[100] All-aged stands are generally more asynchronous and often have greater tree species diversity, but even-aged stands are natural for many temperate species, especially those established through stand replacement fires or other forest-level catastrophic disturbances.

The selection of which trees to cut is a critical aspect of the harvesting decision. Historically, the largest and straightest trees of particular species were preferred, because they produce the most and best wood products. However, leaving smaller trees, those with poorer form, and the less desirable species may result in a degraded forests, especially if these are the trees providing seed for future forests. Salvage and sanitation harvests, however, commonly focus on removing dead, dying, infected/infested, and at-risk trees, and thus can be a component of forest health management. (See above.) Leaving "legacy trees," with their superior growth characteristics and/or resistance to particular insects or diseases,[101] is particularly important, because they can provide seeds for regenerating adaptable forests, as well being healthy, resilient trees themselves.

Rotation age depends largely on the purpose of the forest: industrial plantations may maximize timber production, while conservation areas will likely emphasize tree sizes to maximize other ecosystem services. Lower rotation ages can speed forest adaptation by allowing species better adapted to climate change to regenerate (see below), while reducing forest synchrony and the period of time forests are vulnerable to pests and disease.[102] However, shorter rotation ages also eliminate some ecosystem values associated with very old trees (e.g., habitat for certain animal species and carbon sequestration) and reduces overall stand asynchrony by resulting in fewer age classes of tree stands.

Similarly, cutting unit size generally depends on the purpose of the forest. Larger sizes (40 acres or more for many even-aged forests) generally lower management costs and yield greater harvests in a single cutting operation. Small cutting units can increase biodiversity and stand asynchrony, and thus can contribute to resilient, adaptable forests. However, small cutting units can also cause problems for healthy forests, because they require more roads to remove the same amount of

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[99] See D. Smith et al., *The Practice of Silviculture: Applied Forest Ecology*, 9th ed. (New York: John Wiley & Sons, Inc., 1997).

[100] See CRS Report 98-917, *Clearcutting in the National Forests: Background and Overview*.

[101] J. Agee and C. Skinner, "Basic Principles of Forest Fuel Reduction Treatments," *Forest Ecology and Management*, vol. 211 (2005), pp. 83-96.

[102] Spittlehouse and Stewart, "Forest Adaptation to Climate Change."

biomass. Roads are problematic for forest management, as road construction and inadequate road maintenance are primary sources of erosion and stream sedimentation. In addition, smaller cutting units and more roads contribute to forest fragmentation. (See "Fragmentation and Corridors," below.) All-aged management can intensify the road and fragmentation problems of small cutting units for healthy forests.

Thinning

Thinning is the practice of cutting and removing a portion of the trees in a stand. It is commonly done to enhance timber growth, to reduce wildfire threats by eliminating some fuels (especially fuel ladders); to halt or slow the spread of insect or disease infestations; to remove invasive species; to improve tree vigor; and to provide economic benefits. Because the biomass to be cut and removed is selected, thinning can also be used to enhance forest resilience and adaptability, by encouraging trees that are resistant to disturbances and that can recover more quickly when disturbances occur. At the broader scale, thinning can be used to enhance stand diversity, altering forest structure by removing trees to decrease stand density and uniformity, to increase forest asynchrony, and to expand the age, size, and species diversity of stands.[103] Thinning is not a panacea, however. Many object to the potential impacts of mechanical treatments—soil erosion and water quality degradation; removal of valuable wood rather than improving forest health; short-term increase in fire risk from the small-diameter biomass that remains; and more.[104] On the other hand, while the wood from thinning may have little value for traditional wood products, these activities can increase the supply of wood for biomass energy, offsetting consumption of fossil fuels.

Natural Forest Regeneration

Natural regeneration, generally following a timber harvest, relies on seeds from trees on lands surrounding the cutting units or uncut trees within the cutting units. It can help produce resilient and adaptable forests by providing genetic diversity for new stands, since many trees can provide seed sources for the regrown forest. Also, if the legacy trees and surrounding forest contain a mix of species, the regeneration is likely to reflect that species diversity. However, if historic and current harvests have removed all or most of the desirable (both in species and genetic characteristics) trees, natural regeneration might result in an unhealthy, genetically impoverished stand. Also, naturally regenerated trees sometimes takes several years to become established, which can allow invasive and non-tree species to dominate a site.

Artificial Forest Regeneration

Planting trees established in nurseries, called artificial regeneration, is a common alternative to natural regeneration. Forest management, especially for industrial plantations, has traditionally focused on retaining a few desired, previously established species. However, planting species and species mixes could promote resilient, adaptable forests. Suitability of species for planting could be related to resistance to pests, fire, drought, and other forest stressors. For example, aspen is a relatively short-lived species that recovers quickly from even the most intense fires; thus it could be planted among species slower to recover after fire in areas where fire is expected to

[103] Spittlehouse and Stewart, "Forest Adaptation to Climate Change."

[104] A full discussion of the desirable and undesirable effects of thinning, as well as of logging generally, is beyond the scope of this report. For more information, see pages 9-17 of CRS Report RL31432, *Carbon Sequestration in Forests*.

increase.[105] Because the understanding of future conditions can be ambiguous or uncertain, reforesting with species that are successful under a wide range of conditions seems likely to enhance reforestation success.[106] Caution may be warranted, however, when reforesting with species and species mixes in anticipation of climate change. Some have suggested the need to plant trees beyond (further north and further upslope from) the situations where the species has been planted,[107] but such planting could cause unexpected and unintended consequences, due to the complex nature of ecosystems and species interactions. To the extent that such planting is outside traditional practices, experimentation and monitoring may be necessary to improve the probability of regeneration success without unintended harm to ecosystem services.[108]

Tree nurseries could also contribute to adaptation by providing genetically appropriate planting stock. Trees can be bred for tolerance to stressors. Genetic options are already available for some species, including for drought hardiness, delayed or advanced growth initiation, and pest resistance.[109] Genetic engineering (e.g., genetically modified organisms, or "GMOs") might also be useful, but could be controversial.

Forest Management Certification

Certification of forest management as sustainable might also contribute to forests that are adaptable and resilient. Forest certification organizations emphasize forest sustainability, including low-impact logging practices, and their certifications provide financial incentives (higher wood product prices and sometimes revenues from other ecosystem services) to landowners that encourage biodiversity and other practices that can assist adaptation. Certification is a process by which an independent organization examines forest management according to certain established principles of sustainable forestry to assure that the certified forests will continue to produce the desired ecosystem services (including wood products). There are several sustainable forest certification organizations, including the Forest Stewardship Council (FSC), the Sustainable Forestry Initiative (SFI), the Central Point of Expertise on Timber Procurement (CPET), and the Canadian Standards Association (CSA).[110]

Low-impact logging is a particular practice encouraged by certification that could contribute to sustainable, resilient forests, It is a collection of practices is intended to minimize forest disturbances from harvesting.[111] Although developed largely for tropical forests, where logging can cause extensive damage to the residual trees, low-impact logging practices are relevant to U.S. temperate forests for resilience and adaptation. Some practices, such as designing cutting units to minimize road needs and to protect residual stands, are relatively commonplace in the United States. However, other low-impact logging practices which can aid adaptation are relatively less common, such as leaving legacy-trees, reducing the water quality impacts of road construction and maintenance, and adjusting rotation intervals.

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[105] Spittlehouse and Stewart, "Forest Adaptation to Climate Change."

[106] Spittlehouse and Stewart, "Forest Adaptation to Climate Change."

[107] Millar et al., "Climate Change and Forests of the Future."

[108] Millar et al., "Climate Change and Forests of the Future."

[109] St.Clair and Howe, "Genetic Options for Adapting Forests."

[110] See WWF/World Bank Global Forest Alliance, *Forest Certification Assessment Guide (FCAG): A Framework for Assessing Credible Forest Certification Systems/Schemes*, Washington, DC, June 2006, http://assets.panda.org/downloads/fcagfinal.pdf.

[111] D. Dykstra, *Reduced Impact Logging: Concepts and Issues*, UN Food and Agriculture Organization [FAO] Corporate Document Repository, http://www.fao.org/docrep/005/ac805e/ac805e04.htm.

Fragmentation and Corridors

Fragmented habitats are habitat parcels separated by stretches of other habitat, such as forest patches separated by farmland or housing developments.[112] Species in fragmented habitats have physical barriers to dispersal. Many plant and animal species cannot move readily across farmland, highways, or other breaks in their habitat. Habitat fragmentation adds to the difficulties when ecological habitat shifts out-pace natural species migration rates.[113] (See "Limits to Natural Adaptation," above.) Climate change might move suitable habitats faster than many species can disperse; fragmentation of habitats makes it more difficult for species to disperse to new suitable habitats.[114]

Habitat corridors can eliminate some dispersal barriers.[115] Corridors are landscapes that contain continuous habitat with relatively few physical or biotic barriers to species migration. For most of the continental United States, broad habitat corridors are now fragmented by human land-use developments. Fragmented habitats along migration pathways can sometimes be connected through policies and practices to acquire lands and influence land management and to maintain connectivity where it is threatened. Some suggest designing landscapes to facilitate species spread.[116] Others propose managing landscapes at large scales to maximize connectivity.[117] Both may be difficult, because migration pathways may be more restricted in some places than others, depending on topography and other barriers to dispersal. It can be also difficult because such efforts encompass encouraging multiple landowners to act in coordinated, cohesive ways and may require innovative approaches to encourage species dispersal over a multitude of land uses. It may also require a politically challenging array of regulations and incentives to achieve large-scale connectivity and corridors. Nonetheless, habitat corridors are considered to be one of the least risky adaptation management strategies.[118]

Existing species have migrated or adapted to accommodate climate change in the past. However, given the increasing habitat fragmentation of the past two centuries, it seems likely that restricted natural dispersal of species will result in the extinction of species that might have otherwise survived.[119] Although forests may eventually be productive and valuable after periods of transition, some animal species will likely be lost if corridors do not connect them with suitable habitats.

Managed Relocation

Managed relocation is another management strategy for assisting forest adaptation. Managed relocation (also known as assisted migration or translocation) is the intentional movement of trees

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[112] See K. Riitters, "Fragmentation," in *Forest Resources of the United states, 2007*, ed. W.B. Smith et al. (Washington, DC: USDA Forest Service, 2009), pp. 22-25.

[113] R. Noss, "Beyond Kyoto: Forest Management in a Time of Rapid Climate Change," *Conservation Biology*, vol. 15, no. 3 (2002), pp. 578-590.

[114] O. Honnay et al, "Possible Effects of Habitat Fragmentation and Climate Change on the Range of Forest Plant Species," *Ecology Letters*, vol. 5, no. 4 (July 2002), pp. 525-530.

[115] Griffith, et al., "Adaptation for Wildlife Refuges."

[116] McLachlan et al., "Assisted Migration in an Era of Climate Change."

[117] Millar et al., "Climate Change and Forests of the Future."

[118] Lawler, "Resource Management in a Changing and Uncertain Climate;" and Blate et al., "Adapting to Climate Change in United States National Forests."

[119] McLachlan et al., "Assisted Migration in an Era of Climate Change."

and related species to locations where the probability of future success is predicted to be higher.[120] It is akin to artificial forest regeneration, discussed above, but encompasses the regeneration of whole ecological systems, based on the premise that natural migration may not be able to keep pace with climate change.

Many experts believe managed relocation is a high-risk strategy for adaptation.[121] Due to the complexity of ecosystem community interactions and relationships, managed relocation efforts may require multi-species relocation. Some species depend on others for survival, with relationships ranging from mutualism or symbiosis (where both species benefit) to parasitism (where one species essentially lives off the other). Such community interactions would need to be understood in the ecosystems where species are relocated, to better understand the impacts and feasibility of relocation.[122] Some advocates recommend experimentation with species introductions over a range of habitats, rather than solely within historical habitat, followed by monitoring to assess success.[123]

Effective managed relocation of ecosystems may require more accurate projections of habitat shifts than currently exist. Paleo-ecological data (from pollen records, tree rings, charcoal deposits, animal fossils, and more) and records of historical species ranges may provide insight into forest responses to climate change and natural species migration over longer periods.[124] For example, northern populations of many temperate forest types may be pre-adapted to climate change from previous exposure to population expansion after the last ice age, and might therefore be a logical option for relocation north of current habitats.[125]

Some argue that the species introduced to new areas through managed relocation would be invasive species and the uncertainties about the possible success and impacts of relocation should restrain relocation efforts.[126] Managed relocation clearly can disrupt the communities where relocation is being implemented.[127] Although, ecologists have made a concerted effort to study invasive species, reliable predictions about invasive species dominance remain elusive. It can take decades for invasive species to dominate the ecosystems into which they have been introduced.[128] This suggests efforts to monitor relocated species may be difficult, costly, and long-term. Future research could emphasize species' thresholds to trigger relocation, species prioritization, and best practices for relocation to minimize damage to host ecosystems and the ecosystem services they provide. However, for landowners with extensive holdings, such as some major forest products companies, managed relocation of desirable timber species might be a practical, if expensive, approach to assuring timber supplies and other key ecosystems services in the long term.

[120] D. Richardson et al., "Multidimensional Evaluation of Managed Relocation," *PNAS*, vol. 106, no. 24 (2009), pp. 9721-9724.

[121] Richardson et al., "Multidimensional Evaluation of Managed Relocation."

[122] McLachlan et al., "Assisted Migration in an Era of Climate Change;" Spittlehouse and Stewart, "Forest Adaptation to Climate Change."

[123] Millar et al., "Climate Change and Forests of the Future."

[124] J. Thompson et al, "Is There Potential for the Historical Range of Variability to Guide Conservation Given the Social Range of Variability?" *Ecology and Society*, vol. 14, no. 1 (2008), online article 18.

[125] McLachlan et al., "Assisted Migration in an Era of Climate Change."

[126] Lawler, "Resource Management in a Changing and Uncertain Climate."

[127] McLachlan et al., "Assisted Migration in an Era of Climate Change."

[128] See CRS Report RL30123, *Invasive Non-Native Species: Background and Issues for Congress*, especially pages 7-10.

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